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Influence of conventional and chemical thinning on stand structure and diversity of plant and mammal communities in young lodgepole pine forest

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Abstract

Silvicultural practices that provide a wide variety of vegetative composition and structure (habitats) in young stands should help manage for biological diversity across forested landscapes. This study was designed to test the hypotheses that: (i) abundance and diversity of stand structure attributes (species diversity and structural diversity of herb, shrub and tree layers) and forest floor small mammal communities, and (ii) relative habitat use by large herbivores, will increase from unthinned to conventionally thinned to chemically thinned stands of young lodgepole pine (*Pinus contorta*) forest. Replicate study areas were located near Summerland, Kelowna and Williams Lake in south-central British Columbia, Canada. Each study area had three treatments: a conventionally thinned, a chemically thinned and an unthinned stand. Pre-commercial thinning was conducted in 1993. Coniferous stand structure and understory vegetation were measured prior to thinning in 1993 and 5 years later in 1998. Small mammal populations were sampled intensively from 1993 to 1998. Relative habitat use by large herbivores was sampled in 1998.

Our results indicate that chemical thinning of young lodgepole pine stands produced an aggregated pattern of crop trees compared with stands subjected to conventional thinning. Diameter growth of crop trees in the chemically thinned stands was similar to that in the conventionally thinned, but also to that in unthinned stands. Although horizontal stratification (aggregates of trees) was enhanced, vertical stratification (structural diversity of vegetation) was less in the chemically than conventionally thinned stands. Abundance and diversity of understory vegetation and small mammal communities were generally unaffected by stand thinning in these particular installations. Relative habitat use by mule deer (*Odocoileus hemionus*) occurred in a gradient from highest in the conventionally thinned stand to lowest in the unthinned stand. Habitat use by snowshoe hares (*Lepus americanus*) tended to have the opposite trend. Moose (*Alces alces*) exhibited no difference in habitat use among stands. Thus, although there were few differences among treatment stands, chemical thinning could be used to develop an aggregated pattern of crop trees in pre-commercially thinned stands to maintain habitat for herbivores such as snowshoe hares and mule deer. Understory plant and forest floor small mammal communities would be maintained in these stands as well.

Keywords: Pre-commercial thinning; Stand structure; Understory vegetation; Lodgepole pine; Small mammal communities; Species diversity; Glyphosate herbicide

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1. Introduction

Conservation of biological diversity has been recognized as an important ecological criterion of forest sustainability (Hunter, 1999). Managed forests which have a variety of tree species, successional stages (including old growth forest reserves), stand densities, stand structures, edges and riparian zones in a mosaic of habitats across a landscape should have natural levels of biodiversity (Hunter, 1990, 1999). Spatial heterogeneity is an integral part of dynamic forest mosaics, and hence, conservation of biodiversity (Spies and Turner, 1999). Forestry practices that provide a wide variety of vegetative composition and structure (habitats) in young plantations and stands should help manage for diversity at a landscape-scale.

Many silvicultural practices such as planting cutover forest lands, vegetation management techniques and stand thinning have been criticized for creating relatively uniform conditions within forest stands (Kimmins, 1992). Pre-commercial thinning, in particular, tends to leave a homogeneous array of trees throughout a treated stand. This practice contributes to both volume and quality increases in wood fiber on those crop trees selected for superior growth and form during the thinning process (Johnstone, 1985). Thinning is also a technique that alters stand structure and ecological succession of understory vegetation. Conventional stand thinning generally leads to positive responses in biomass of understory vegetation (Crouch, 1986; Hungerford, 1987; Klinka et al., 1996; Stone and Wolfe, 1996; Thomas et al., 1999; Sullivan et al., 2001). Thus, there is an opportunity to increase stand-level diversity in thinned stands in terms of understory vegetation. This diversity could be further enhanced if the thinning operation was less uniform, thereby leaving crop trees in an irregular pattern of tree patches and openings similar to a naturally regenerated forest.

An alternative method for pre-commercial thinning of young stands is the use of herbicide to act as a chemical thinning agent (Crossley, 1956; MacLaren et al., 1999). Trees are sprayed or injected with a herbicide and killed trees remain as snags for some time after treatment. Conventional thinning is usually done with chain-saws and the thinned trees remain as slash on the ground. In addition, the chemical thinning operation tends to leave some patches or clumps of crop trees because the efficacy of thinning is less precise than that achieved by conventional cutting and falling of thinned trees.

Young coniferous stands often have communities of forest floor small mammals that are an integral part of wildlife diversity in these early successional stages. Small mammals have important functional links in forest ecosystem dynamics because they are dispersal agents for mycorrhizal fungi (Maser et al., 1978), consumers of plants and plant products (Sullivan et al., 1990; Carey et al., 1999) and invertebrates (Buckner, 1966), and a prey source for a diverse community of furbearers and raptors (Martin, 1994; Carey and Johnson, 1995). Despite these important roles, there is little information on the influence of pre-commercial thinning on diversity of plant and small mammal communities.

In addition, several studies have related increases in forage production to increased habitat use by mammalian herbivores in lodgepole pine (*Pinus contorta*) stands during certain seasons (Blair and Enghardt, 1976; Crouch, 1986; Lyon, 1987; Sullivan and Sullivan, 1988).

Thus, this study was designed to test the hypotheses that: (i) abundance and diversity of stand structure attributes (species diversity and structural diversity of herb, shrub and tree layers) and forest floor small mammal communities, and (ii) relative habitat use by large herbivores, will increase from unthinned to conventionally thinned to chemically thinned stands of young lodgepole pine forest.

2. Methods

2.1. Study areas

Three study areas were chosen on the basis of having candidate stands of young (12–14 years old) lodgepole pine that had relatively uniform tree cover, comparable diameter, height and density of trees prior to stand treatments. Location, proximity (boundaries) and size of candidate stands were determined by a balance between adequate interspersion of experimental units (Hurlbert, 1984) and the logistics and access for conducting operational-scale treatments.

The Summerland study area was located in the Bald Range, 25 km west of Summerland in south-central British Columbia, Canada (49°40′N; 119°53′W). This area is within the Montane Spruce dry-mild (MS_{dm})

biogeoclimatic zone (Meidinger and Pojar, 1991) at an elevation range of 1450–1520 m with gently rolling topography and sandy loam soil. The MS has a cool, continental climate with cold winters and moderately short, warm summers. Mean annual temperature is 0.5–4.7 °C and precipitation ranges from 380 to 900 mm. The MS landscape has extensive, young and maturing seral stages of lodgepole pine, that have regenerated after wildfire. Hybrid interior spruce (*Picea glauca* × *P. engelmannii*) and subalpine fir (*Abies lasiocarpa*) are the dominant shade-tolerant climax trees. Douglas-fir (*Pseudotsuga menziesii*) is an important seral species in zonal ecosystems and is a climax species on warm south-facing slopes in the driest ecosystems. Trembling aspen (*Populus tremuloides*) is a common seral species and black cottonwood (*P. trichocarpa*) occurs on some moist sites (Meidinger and Pojar, 1991).

Clear-cut harvesting of lodgepole pine with some uniform and group seed-tree reserves of Douglas-fir began in this area in 1978 in response to an outbreak of mountain pine beetle (*Dendroctonus ponderosae*). Depending on the original composition of the harvested stands and the degree of windthrow damage after harvesting, the number of residual Douglas-fir ranged from 0 to 2 trees per ha in our candidate stands. Lodgepole pine regenerated naturally after harvesting and was the dominant tree species in these young stands ranging from 9980 to 11 150 total stems/ha. Minor components of the stands included Douglas-fir, interior spruce, subalpine fir, Ponderosa pine (*P. ponderosa*), willow (*Salix* sp.), Sitka alder (*Alnus sinuata*) and trembling aspen.

In 1993 at the start of the study, dbh (diameter at breast height, 1.3 m above the soil surface) ranged from 2.2 ± 0.1 cm (mean ± S.E.) to 3.2 ± 0.1 cm with a mean age of 12–14 years. Stand height ranged from 2.3 ± 0.1 to 3.1 ± 0.1 m. In 1998, the mean stand diameter ranged from 5.0 ± 0.1 to 7.7 ± 0.1 cm and mean stand height ranged from 4.1 ± 0.1 to 4.9 ± 0.1 m (Table 1). Area of stands ranged from 2.9 to 5.0 ha.

The Kelowna study area was located 37 km northwest of Kelowna, BC (50°04′N; 119°34′W) in the $\mathrm{MS_{dm}}$ biogeoclimatic subzone. Topography of this area is also gently rolling to flat with sandy loam soil at 1220–1240 m elevation. This area was clear-cut harvested in 1979–1980 and also regenerated naturally to lodgepole pine to a mean pre-thinning density of 8686 stems/ha, with the other coniferous species, including western larch (*Larix occidentalis*), as minor components.

In 1993, the mean stand diameter and height ranged from 3.1 ± 0.1 to 4.5 ± 0.1 cm and 3.0 ± 0.1 to 3.9 ± 0.1 m, respectively, with a mean stand age of 12–13

Table 1
Characteristics of lodgepole pine stands at the Summerland, Kelowna and Cariboo study areas, BC

Study area and stand	Density (stems/ha >3 m ht)		Total conifers/ha	Area (ha)	*N*	$\chi \pm 1$ S.E.			
						dbh (cm)		Height (m)	
	1993	1998				1993	1998	1993	1998
Summerland									
A	936	852	3066	4.5	289	3.20 ± 0.09	7.70 ± 0.12	2.83 ± 0.04	4.54 ± 0.05
B	1000	2400	5625	2.9	187	3.92 ± 0.11	7.64 ± 0.15	3.12 ± 0.05	4.86 ± 0.06
C[a]	10700	12340	12810	5.0	200	2.20 ± 0.07	4.96 ± 0.12	2.34 ± 0.05	4.14 ± 0.05
Kelowna									
A	1004	967	3383	9.5	237	4.30 ± 0.10	8.32 ± 0.14	3.75 ± 0.06	5.76 ± 0.07
B	1000	1985	4100	2.0	200	4.53 ± 0.12	8.08 ± 0.16	3.85 ± 0.08	6.27 ± 0.10
C[a]	4029	4090	6455	12.6	195	3.14 ± 0.13	6.22 ± 0.19	3.03 ± 0.07	5.30 ± 0.09
Cariboo									
A	980	884	3327	4.3	185	5.51 ± 0.15	9.43 ± 0.19	4.77 ± 0.09	7.66 ± 0.11
B	1233	1080	2495	1.8	191	6.45 ± 0.16	10.34 ± 0.20	4.20 ± 0.09	6.95 ± 0.12
C[a]	2915	2405	3680	3.3	199	5.61 ± 0.16	8.50 ± 0.22	4.38 ± 0.10	7.48 ± 0.13

[a] Density of lodgepole pine includes all height classes.

years. In 1998, the mean stand diameter ranged from 6.2 ± 0.2 to 8.3 ± 0.1 cm and mean stand height ranged from 5.3 ± 0.1 to 6.3 ± 0.1 m (Table 1). Area of stands ranged from 2.0 to 12.6 ha.

The Cariboo study area was located in the Alex Fraser Research Forest (University of British Columbia), 75 km northeast of Williams Lake, BC (52°29′N; 121°45′W) in the sub-boreal spruce dry-warm (SBS_{dw}) biogeoclimatic zone (Meidinger and Pojar, 1991). The general topography is gently rolling to flat at 850–870 m elevation. In mature stands, interior spruce, subalpine fir, and some Douglas-fir are mixed with extensive stands of lodgepole pine, that regenerated after wildfires. This area is an 80 ha unit that was clear-cut harvested in 1976, followed by some natural regeneration and some planting of lodgepole pine in 1983. Mean pre-thinning stand density was 3333 stems/ha.

In 1993, the mean stand diameter and height ranged from 5.5 ± 0.2 to 6.5 ± 0.2 cm and 4.2 ± 0.1 to 4.8 ± 0.1 m, respectively, with a mean stand age of 13 years. In 1998, the mean stand diameter ranged from 8.5 ± 0.2 to 10.3 ± 0.2 cm and mean stand height ranged from 7.0 ± 0.1 to 7.7 ± 0.1 m (Table 1). Area of stands ranged from 1.8 to 4.3 ha.

2.2. Experimental design and stand treatments

The three study areas acted as regional replicates (blocks). Within each replicate, there were three experimental units (stands) which had lodgepole pine stands treated in the following randomized block design. Stand A was conventionally thinned to a target of 1000 stems/ha; Stand B was chemically thinned to a target of 1000 stems/ha; Stand C was unthinned.

Pre-commercial thinning was conducted at an operational-scale, based on forest management activities, at all study areas in the fall of 1993. These installations were established at this scale to allow measurement of both vegetation and wildlife responses to treatments, at least at the Summerland and Kelowna study areas. Wildlife responses were not measured at the Cariboo study area because the installations were too small to provide meaningful samples. Conventional thinning was done with chainsaws; chemical thinning used Ezject® Selective injection herbicide capsules containing Vision® glyphosate herbicide (*N*-phosphonomethyl glycine in the form of its isopropylamine salt) as the active ingredient. Each capsule contained 0.15 g glyphosate and 1–3 capsules were injected into each thinned tree; number of capsules used per tree was dependent on tree diameter. Dose rate of glyphosate ranged from 0.32 to 0.67 kg/ha in the three chemically thinned stands.

2.3. Tree growth and stand structure

All sampling of lodgepole pine crop trees was done with variable-radius plots to accommodate variations in stand density. Sampling plots were distributed evenly every 50 m along compass lines (50 m apart) that covered the area of each stand. Sample plots (range 19–29) were established in each of the three stands at a given study area. The 10 crop trees closest to each plot center were permanently tagged for a sample of 190–290 trees per stand. The 10 potential crop trees closest to each plot center were sampled in the unthinned stand at each study area. Crop trees were chosen on the basis that those trees would be left as the future crop if the stand was thinned.

Measurement of the total height (m) and dbh (cm) at a permanent reference point were done after thinning at the initial sampling period in the fall of 1993, and 5 years after thinning in the fall of 1998. Height (cm) and width (cm) of tree crowns of sample trees in every other plot in each stand were also measured in 1998 (after Schmidt and Seidel, 1988).

2.4. Stand structure

Sampling of coniferous tree layers in 0–1, 1–2, 2–3 and >3 m height classes was done in a 5.64 m radius circular plot (100 m^2) located in the center of each permanent crop tree plot. This sampling was conducted in the three stands at each study area in 1998 and represented a measure of the stand structure of coniferous trees in each stand over the 5-year post-treatment period.

Down wood was recorded along two transect lines of 20 m each at five locations in each stand in 1998. As each piece was encountered, the following attributes were recorded: (a) diameter (cm) where line crosses wood, and (b) hardness (five decay classes). Volume of down wood (m^3/ha) was calculated by the method of Van Wagner (1968).

2.5. Understory vegetation

Three 25 m transects, consisting of five 5 m × 5 m plots were systematically located in each stand following the method of Stickney (1980). This selection of sites allowed sampling of a range of moisture and nutrient regimes while minimizing variation in vegetation, soil and micro-topographic characteristics within a transect. Each plot contained three sizes of nested subplots: a 5 m × 5 m plot for sampling trees, a 3 m × 3 m subplot for sampling shrubs and a 1 m × 1 m subplot for sampling herbs. Tree, shrub and herb layers were subdivided into height classes: 0–0.25, 0.25–0.5, 0.5–1.0, 1.0–2.0, 2.0–3.0 and 3.0–5.0 m (Walmsley et al., 1980). A visual estimate of percentage cover of the ground was made for each species height class combination within the appropriate nested subplot. Total percentage cover for each layer was also estimated. These data were then used to calculate crown volume index (m^3/0.01 ha) for each plant species (Stickney, 1980, 1985). The product of percent cover and representative height gives the volume of a cylindroid which represents the space occupied by the plant in the community. Crown volume index values were then averaged by species for each plot size and converted to 0.01 ha base to produce a tabular value given for each species and layer (herbs, shrubs and trees). Sampling was done in July–August 1993 in the pre-treatment year and again in July–August 1998. Grasses were not identified to species. Plant species were identified in accordance with Hitchcock and Cronquist (1973), Parish et al. (1996) and MacKinnon et al. (1992).

2.6. Small mammal communities

Forest floor small mammal populations were sampled at 3-week intervals from June to October 1993 and May to October 1994, and at 4-week intervals from May to October of 1995 to 1998 in all stands at the Summerland and Kelowna study areas. Small mammals were not sampled at the Cariboo study area. Trapping grids (1 ha) had 49 (7 × 7) trap stations at 14.29 m intervals with one Longworth live-trap at each station (Ritchie and Sullivan, 1989). Traps were supplied with whole oats, carrot and cotton as bedding. Traps were set on the afternoon of day 1, checked on the morning and afternoon of day 2 and morning of day 3, and then locked open between trapping periods.

Forest floor small mammal species sampled by this procedure included the deer mouse (*Peromyscus maniculatus*), northwestern chipmunk (*Tamias amoenus*), meadow vole (*Microtus pennsylvanicus*), long-tailed vole (*M. longicaudus*), southern red-backed vole (*Clethrionomys gapperi*), heather vole (*Phenacomys intermedius*), montane shrew (*Sorex monticolus*), common shrew (*S. cinereus*) and short-tailed weasel (*Mustela erminea*).

All small mammals (except shrews and weasels) captured were ear-tagged and released at the point of capture immediately after processing (Krebs et al., 1969). There was a high mortality rate for shrews because of the overnight trapping technique. Shrews that died in traps were collected and identified according to Nagorsen (1996).

Population estimates of the deer mouse, northwestern chipmunk, meadow vole and long-tailed vole were derived from the Jolly-Seber stochastic model (Seber, 1982). The minimum number of animals (MNA) known to be alive (Krebs, 1966) was used as the population estimate for the first and last sampling weeks of the study when the Jolly-Seber estimate could not be calculated. Reliability of the Jolly-Seber model declines when population sizes are very low and no marked animals are captured (Krebs et al., 1986). In those cases, the total number of individuals captured was used to compare populations of the southern red-backed vole, montane shrew, common shrew and short-tailed weasel.

2.7. Large herbivores

Relative habitat use by mule deer (*Odocoileus hemionus*) and moose (*Alces alces*) was sampled by fecal pellet groups (Neff, 1968; Loft and Kie, 1988; Edge and Marcum, 1989) on 5 m^2 circular plots located systematically throughout each stand at the Summerland and Kelowna study areas. A pellet group had to have at least 20 pellets. Pellet groups located on the edge of a sample plot had to have 50% or more of the group within the plot in order to be counted. Individual fecal pellets of snowshoe hare (*Lepus americanus*) were also sampled within these circular plots as a measure of relative habitat use by this animal. Plots were sampled for pellets in the fall of

1998 and represent habitat use over the 5-year post-treatment period. Numbers of sample plots ranged from 95 to 145 per stand at each of the study areas.

2.8. Diversity measures

Habitat diversity was measured by species richness, species diversity and structural diversity. Species richness was the total number of species sampled for the plant (herbs, shrubs and trees) and small mammal communities in each stand (Krebs, 1989). Species diversity was based on the Shannon–Wiener (Pielou, 1966) diversity index which is well represented in the ecological literature (Magurran, 1988; Burton et al., 1992). Structural diversity utilized the Shannon–Wiener index with plant species represented by height classes and the amount (crown volume index) of vegetation in each class. Density of trees in each height class was used in these calculations of structural diversity for coniferous trees.

For the plant communities, species diversity was calculated using the crown volume index for each plant species averaged across the three transects, each of which was an average of five subplots, in a given stand. Species diversity was calculated separately for herbs, shrubs and trees. Diversity for small mammals was calculated using the estimated abundance of each species for a given sampling period and averaged over the number of sampling periods for each year.

2.9. Statistical analysis

For the tree measurements, data were summarized according to initial diameter and height classes, and this format was maintained throughout the analyses. Because growth rates are dependent on initial diameter and height, an analysis of covariance (ANCOVA) was used to generate adjusted mean 5-year diameter and height increments of crop trees for the three stands at each study area. A randomized block ANOVA (Zar, 1984) was conducted to test differences in mean diameter and height increments and mean crown volume of crop trees, mean density, species diversity, and structural diversity of coniferous trees, and mean volume, diameter, and decay classes of down wood among treatment stands for the 5-year period since stand thinning. Mean crown volume index, species richness and species diversity of herbs, shrubs and trees, and total structural diversity of all vegetation layers were also compared among treatment stands in 1993 and 1998 by this randomized block ANOVA.

Measurement of the spatial patterning or dispersion of lodgepole pine crop trees used a variance/mean ratio (Krebs, 1989) and Morisita's index of dispersion (Morisita, 1962). In these indices of dispersion, a random pattern $= 1$, a uniform pattern is <1 and a clumped or aggregated pattern is >1. The variance/mean ratio test for a clumped distribution used a χ^2 analysis.

A randomized block ANOVA was also used to test differences in mean total abundance of small mammals, mean abundance of each species and mean species richness and mean species diversity of the small mammal communities. For these analyses, a mean estimate of a given parameter for each year and treatment was derived to use the variability among years and blocks to test for differences among levels of the treatment. Thus, there were 10 replicates (two spatial × five temporal) for the pooled small mammal data in 1994–1998.

Mean values and 95% confidence intervals were calculated for crown volume of crop trees, plant species diversity, total species richness and total structural diversity of plant communities to compare treatments over the 5-year post-treatment period. Duncan's multiple range test (DMRT) was used to compare mean values. In all analyses, the level of significance was at least $p = 0.05$.

3. Results

3.1. Tree growth and stand structure

Mean 5-year diameter increment was significantly $(F_{2,4} = 8.85; p = 0.03)$ different among stands with the conventionally thinned stand higher than that of the unthinned (Table 2). Mean 5-year height increment was similar $(F_{2,4} = 3.77; p = 0.12)$ among stands (Table 2). Mean crown volume (m^3/tree) was also similar $(F_{2,4} = 5.50; p = 0.07)$ among stands. However, the chemically thinned stands at Summerland and Cariboo had a greater mean volume of tree crowns than the unthinned stands, based on non-overlapping 95% confidence intervals (Fig. 1). Mean

Table 2
Summary of diameter and height growth increments of lodgepole pine crop trees and density, species diversity, and structural diversity of all coniferous trees at 5 years post thinning, together with results of ANOVA's, for the conventionally thinned (ConvThin), chemically thinned (ChemThin) and unthinned stands[a]

Variable	Stands[b]			$F_{2,4}$	p
	ConvThin	ChemThin	Unthinned		
Diameter (cm)	4.12 a ± 0.18	3.59 ab ± 0.13	3.06 b ± 0.12	8.85	0.03
Height (m)	2.16 ± 0.32	2.33 ± 0.32	2.41 ± 0.38	3.77	0.12
Density (ha)	3258.7 ± 97.7	4180.0 ± 996.7	7648.3 ± 2702.3	2.69	0.18
Species diversity	1.16 ± 0.24	0.92 ± 0.28	0.94 ± 0.34	2.22	0.22
Structural diversity	1.64 ± 0.09	1.67 ± 0.07	1.59 ± 0.13	0.12	0.89

[a] Data are means ± 1 S.E. ($n = 3$).

[b] Mean values followed by different letters are significantly different by DMRT.

total density ($F_{2,4} = 2.69; p = 0.18$), species diversity ($F_{2,4} = 2.22; p = 0.22$) and structural diversity ($F_{2,4} = 0.12; p = 0.89$) of coniferous trees at 5 years post treatment were all similar among stands (Table 2).

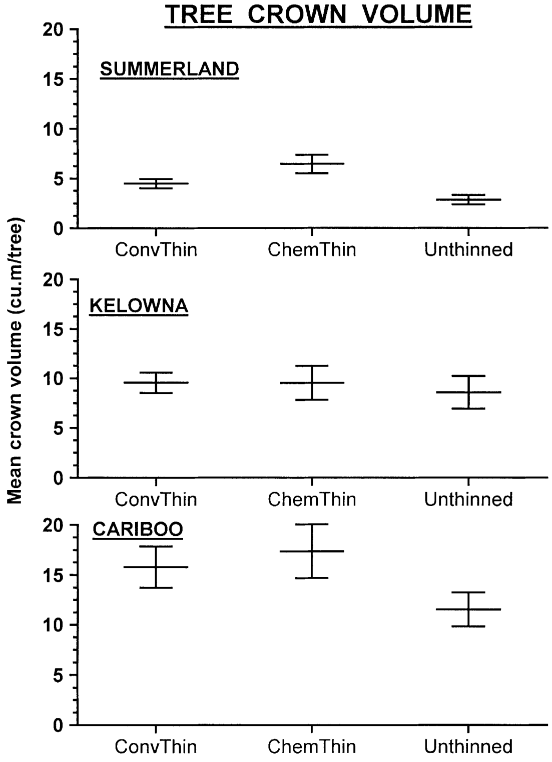

Fig. 1. Mean (±95% confidence intervals) crown volume (m^3/tree) of crop trees in the conventionally thinned (ConvThin), chemically thinned (ChemThin) and unthinned stands at Summerland (top), Kelowna (middle) and Cariboo (bottom) study areas in 1998.

Mean volume (m^3/ha) of down wood was similar ($F_{2,4} = 0.55; p = 0.62$) among treatment stands, ranging from 64.88 to 88.55, at 5 years post treatment (Table 3). However, the conventionally thinned stands had a greater number of wood pieces in the <5 cm ($F_{2,4} = 43.48; p < 0.01$) and 5–25 cm ($F_{2,4} = 8.16; p = 0.04$) diameter classes than either of the other treatment stands (DMRT; $p = 0.05$). Similarly, there was a significant ($F_{2,4} = 82.11; p < 0.01$) difference among stands in the number of wood pieces in the most common decay class 3. The conventionally thinned stands had 3.32 times more wood in that state of decay than the chemically thinned stands and 16.06 times more than in the unthinned stands (DMRT; $p = 0.05$). The chemically thinned stands had 4.84 times more decay class 3 wood pieces than the unthinned stands (Table 3).

The spatial patterning or dispersion of lodgepole pine crop trees indicated a significant degree of clumping or aggregation of trees in the chemically thinned and unthinned stands at Summerland and Kelowna (Table 4). Although the conventionally thinned stand exhibited a clumped pattern of trees at Kelowna, the degree of dispersion was 6.9–8.7 times higher in the chemically thinned and unthinned stands for the variance/mean ratio. Both conventionally and chemically thinned stands in the Cariboo had a uniform dispersion of trees compared with the unthinned stand (Table 4).

3.2. Understory vegetation

Mean total crown volume index of herbs, shrubs and trees were similar among stands in 1993 and 1998

Table 3
Summary of characteristics of down wood (volume in m^3/ha and number of pieces of wood in diameter classes and decay classes) together with results of ANOVA's for conventionally thinned (ConvThin), chemically thinned (ChemThin) and unthinned stands at the three study areas[a]

Variable	Stands[b]			$F_{2,4}$	p
	ConvThin	ChemThin	Unthinned		
Volume (m^3/ha)	88.55 ± 24.99	64.88 ± 12.20	84.94 ± 18.47	0.55	0.62
No. of wood pieces					
Diameter class <5 cm	99.20 a ± 6.66	37.13 b ± 7.53	10.20 b ± 1.86	43.48	<0.01
Diameter class 5–25 cm	27.80 a ± 7.40	17.73 b ± 4.92	14.20 b ± 4.16	8.16	0.04
Diameter class >25 cm	0.07 ± 0.07	0.13 ± 0.07	0.73 ± 0.64	1.17	0.40
Decay classes					
1	0.00	0.00	0.00	–	–
2	1.00 ± 1.00	3.40 ± 3.00	0.07 ± 0.07	1.24	0.38
3	100.67 a ± 7.45	30.33 b ± 3.30	6.27 c ± 1.98	82.11	<0.01
4	17.53 ± 6.28	14.60 ± 4.82	10.27 ± 1.68	1.72	0.29
5	8.67 ± 3.71	6.67 ± 2.77	8.53 ± 4.18	0.76	0.53

[a] Data are means ± 1 S.E. $(n = 3)$.
[b] Mean values followed by different letters are significantly different by DMRT.

(Table 5). Similarly, there were no differences $(p > 0.05)$ among stands for species richness or species diversity of herbs, shrubs and trees in 1993 or 1998. Species diversity of plants did not change from 1993 to 1998 based on mean values and 95% confidence intervals (Fig. 2). Total species richness of plants was also similar from 1993 to 1998, but total structural diversity did decline significantly in the chemically thinned stands (Fig. 3). Total structural diversity of vegetation layers was similar between 1993 and 1998 for the conventionally thinned and unthinned stands.

Table 4
Indices of spatial patterning (dispersion) of lodgepole pine crop trees (>3 m height) at 5 years post thinning for the conventionally thinned (ConvThin), chemically thinned (ChemThin) and unthinned stands at each study area

Index and test	ConvThin	ChemThin	Unthinned
Variance/mean ratio			
Summerland	0.91	8.64	25.60
χ^2	25.51(±28)	164.08(±19)	486.39(±19)
p	0.60	<0.01	<0.01
Kelowna	1.60	11.00	13.94
χ^2	36.77(±23)	209.00(±19)	264.93(±19)
p	0.03	<0.01	<0.01
Cariboo	0.31	0.37	6.23
χ^2	5.49(±18)	6.96(±19)	118.38(±19)
p	1.00	0.99	<0.01
Morisita's index of dispersion			
Summerland	0.99	1.30	1.35
Kelowna	1.06	1.48	1.42
Cariboo	0.93	0.94	1.22

Prominent herb species in these stands included fireweed (*Epilobium angustifolium*), grasses, Arctic lupine (*Lupinus arcticus*), wild strawberry (*Fragaria virginiana*), heart-leaved arnica (*Arnica cordifolia*), white-flowered hawkweed (*Hieracium albiflorum*), showy aster (*Aster conspicuus*), bunchberry (*Cornus canadensis*) and one-sided wintergreen (*Orthilia secunda*). Shrub layers in these stands were composed primarily of Sitka alder, twinflower (*Linnaea borealis*), willow, wild rose (*Rosa* sp.), black twinberry (*Lonicera involucrata*) and various species of *Vaccinium*.

3.3. Small mammal communities

Population changes for total abundance of all small mammals in the three treatment stands are illustrated in Figs. 4 and 5 for Summerland and Kelowna, respectively. Total numbers were similar $(F_{2,2} = 0.36; p = 0.74)$ in the pre-treatment year 1993. Over the 5-year post-treatment period, total mean numbers of small mammals were also similar $(F_{2,18} = 1.69; p = 0.21)$ (Table 6). Abundance of small mammals appeared highest in 1994 compared with other

Table 5
Mean ± 1 S.E. ($n = 3$) crown volume index (m^3/0.01 ha) of herbs, shrubs and trees in 1993 (pre-treatment) and 1998 (5 years post treatment), together with results of ANOVA's, for the conventionally thinned (ConvThin), chemically thinned (ChemThin) and unthinned stands

Layer and year	Stands			$F_{2,4}$	p
	ConvThin	ChemThin	Unthinned		
Herbs					
1993	13.68 ± 3.38	14.75 ± 5.53	16.68 ± 2.96	0.79	0.51
1998	12.94 ± 2.91	14.07 ± 1.67	20.00 ± 4.90	1.51	0.32
Shrubs					
1993	9.94 ± 2.39	15.59 ± 6.11	12.98 ± 5.76	0.54	0.62
1998	13.09 ± 4.87	8.58 ± 2.15	16.79 ± 6.84	0.49	0.65
Trees					
1993	74.88 ± 6.72	91.50 ± 7.23	73.27 ± 21.12	0.52	0.63
1998	75.43 ± 13.14	118.27 ± 26.64	166.00 ± 23.79	4.61	0.09

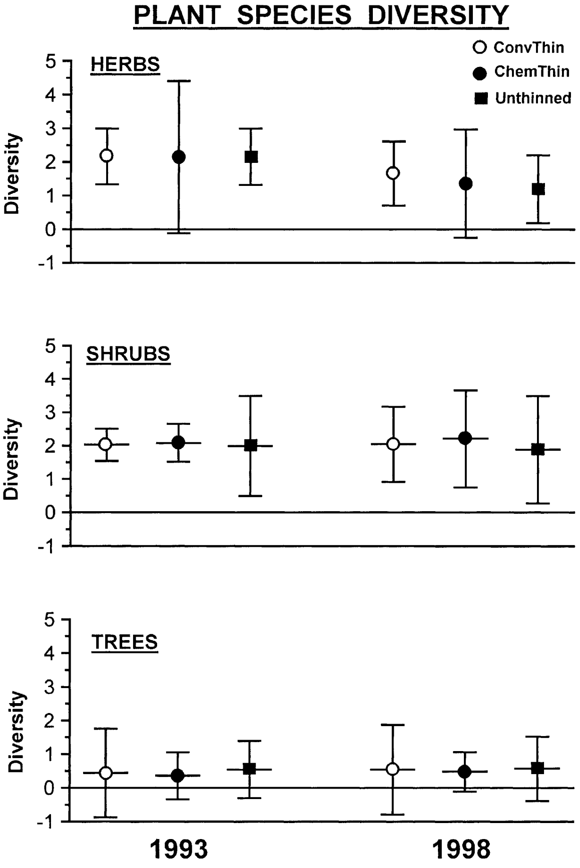

Fig. 2. Means ± 95% confidence intervals ($n = 3$) for species diversity of herbs (top), shrubs (middle) and trees (bottom) for the conventionally thinned (ConvThin), chemically thinned (ChemThin) and unthinned stands in 1993 and 1998.

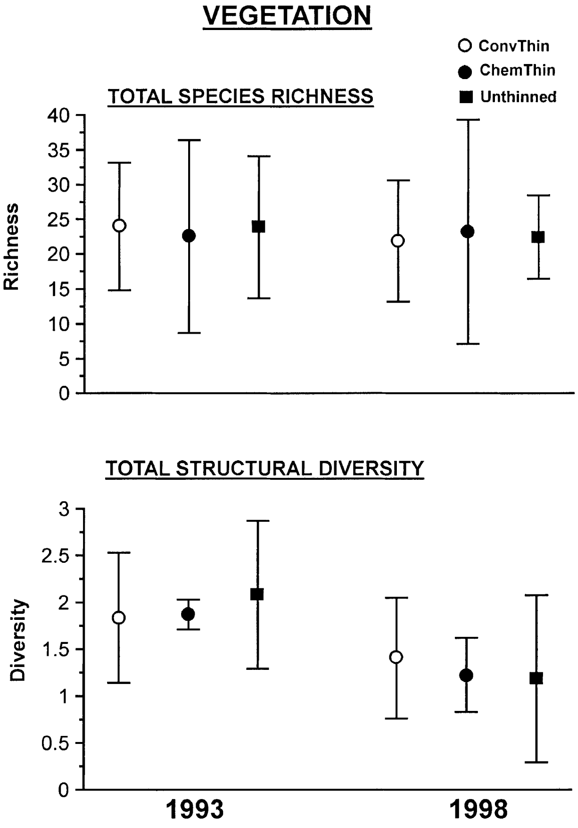

Fig. 3. Means ± 95% confidence intervals ($n = 3$) for total species richness (top) and total structural diversity (bottom) for herbs, shrubs and trees for the conventionally thinned (ConvThin), chemically thinned (ChemThin) and unthinned stands in 1993 and 1998.

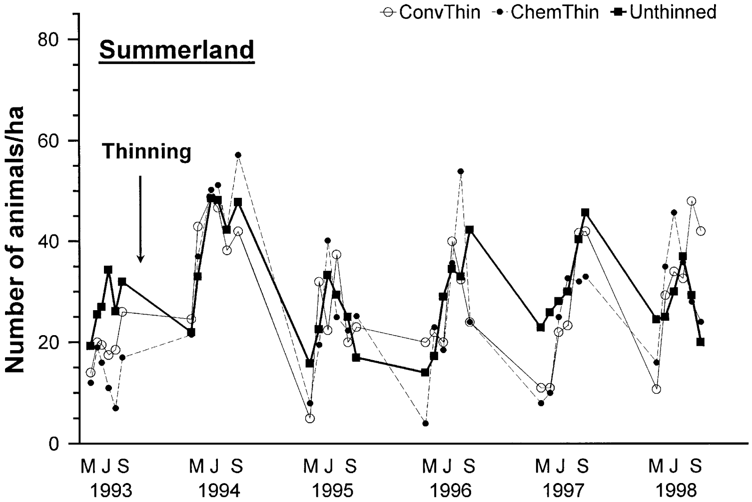

Fig. 4. Total abundance of small mammals per ha in the conventionally thinned (ConvThin), chemically thinned (ChemThin) and unthinned stands at Summerland from 1993 to 1998.

years and there was a strong seasonal fluctuation in numbers in all years (Figs. 4 and 5). The thinned stands at Summerland had marked low spring numbers in 4 of 5 years (Fig. 4). This pattern was not as prevalent at Kelowna where numbers of small mammals in the thinned stands did not exhibit the annual declines observed at Summerland (Fig. 5).

Mean species richness ($F_{2,2} = 0.14; p = 0.88$)and species diversity ($F_{2,2} = 8.86; p = 0.10$) were similar among pre-treatment stands in 1993. These values were also similar in 1998: species richness ($F_{2,18} = 1.06; p = 0.37$) and species diversity ($F_{2,18} = 2.13$; $p = 0.15$). Mean numbers of deer mice (ranging from 7 to 14 animals/ha) were significantly ($F_{2,18} = 17.44$; $p < 0.01$) different among treatment stands with highest abundance in the chemically thinned stands followed by the unthinned and conventionally thinned stands (DMRT; $p = 0.05$) (Table 6). Mean abundance

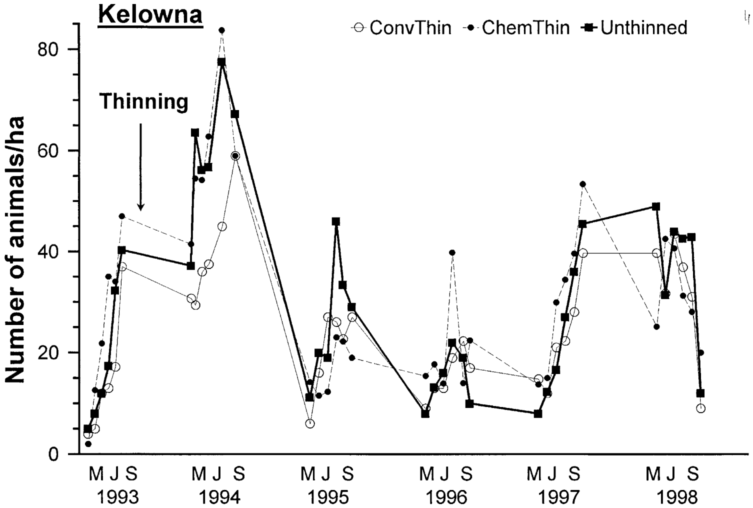

Fig. 5. Total abundance of small mammals per ha in the conventionally thinned (ConvThin), chemically thinned (ChemThin) and unthinned stands at Kelowna from 1993 to 1998.

Table 6
Mean ± S.E. ($n = 10$) abundance per ha of small mammal species during the 5-year post-treatment period in the conventionally thinned (ConvThin), chemically thinned (ChemThin) and unthinned stands for Jolly-Seber population estimates, together with results of ANOVA's[a]

Species	ConvThin	ChemThin	Unthinned	$F_{2,18}$	p
Deer mouse	7.08 c ± 1.61	14.26 a ± 2.67	9.92 b ± 1.75	17.44	<0.01
Long-tailed vole	4.15 ± 1.68	3.74 ± 1.82	7.07 ± 3.11	2.96	0.08
Meadow vole	6.41 ± 1.85	2.85 ± 0.85	2.72 ± 0.97	2.66	0.10
Heather vole	0.82 a ± 0.28	0.15 b ± 0.03	0.30 b ± 0.10	5.08	0.02
Red-backed vole	0.62 ± 0.31	0.98 ± 0.44	1.75 ± 0.69	1.84	0.19
Northwestern chipmunk	4.82 ± 1.18	5.68 ± 1.23	6.95 ± 0.36	2.30	0.13
Montane shrew	3.12 ± 0.55	2.48 ± 0.41	2.52 ± 0.34	1.89	0.18
Common shrew	0.32 ± 0.09	0.40 ± 0.08	0.22 ± 0.05	2.30	0.13
Short-tailed weasel	0.07 ± 0.04	0.10 ± 0.07	0.08 ± 0.05	0.60	0.56
Total	27.91 ± 2.57	30.83 ± 3.90	31.44 ± 3.88	1.69	0.21
Species richness	4.83 ± 0.21	4.78 ± 0.39	5.12 ± 0.20	1.06	0.37
Species diversity	1.79 ± 0.05	1.69 ± 0.12	1.90 ± 0.08	2.13	0.15

[a] Mean values followed by different letters are significantly different by DMRT.

Table 7
Mean ± S.E. ($n = 2$) number of pellets (snowshoe hare) or pellet groups (deer and moose) per ha during the 5-year post-treatment period in the conventionally thinned (ConvThin), chemically thinned (ChemThin) and unthinned stands, together with results of ANOVA's[a]

Species	ConvThin	ChemThin	Unthinned	$F_{2,2}$	p
Snowshoe hare ($\times 10^3$)	1.61 ± 1.1	13.6 ± 1.1	41.7 ± 13.4	6.87	0.13
Mule deer	608.6 a ± 108.5	340.0 b ± 80.0	160.0 c ± 60.0	85.95	<0.01
Moose	6.9 ± 6.9	190.0 ± 150.0	80.0 ± 40.0	1.31	0.43

[a] Mean values followed by different letters are significantly different by DMRT.

of the heather vole was also significantly ($F_{2,18} = 5.08; p = 0.02$) different among stands with the highest numbers in the conventionally thinned stand (DMRT; $p = 0.05$). Numbers of this uncommon vole ranged from 0.15 to 0.82 animals/ha. Mean numbers of the other small mammal species were similar among treatment stands (Table 6).

3.4. Large herbivores

Relative habitat use, based on counts of fecal pellets or pellet groups, was similar among stands for the snowshoe hare ($F_{2,2} = 6.87; p = 0.13$) and moose ($F_{2,2} = 1.31; p = 0.43$) over the 5-year post-treatment period (Table 7). Habitat use by mule deer was significantly ($F_{2,2} = 85.95; p < 0.01$) different among stands with highest use of the conventionally thinned stands followed by the chemically thinned stands and unthinned stands (DMRT; $p = 0.05$). Although not significant, relative habitat use by snowshoe hares, based on number of pellets, was 8.5 times higher in the chemically thinned than conventionally thinned stands. Similarly, hare pellets were 3.1–25.9 times higher in the unthinned than chemically thinned or conventionally thinned stands, respectively (Table 7).

4. Discussion

4.1. Conventional vs chemical thinning

Our study is the first investigation of an alternative method of pre-commercial thinning of young conifer stands and its influence on stand structure and plant and mammal diversity. Conventional thinning of coniferous stands is usually done with chain-saws and the thinned trees are immediately transformed to slash on the ground. Chemical thinning leaves trees standing for some years after thinning. These different techniques were predicted to affect stand structure in terms of available light and fallen debris on the forest floor. In addition, the less uniform treatment of chemical thinning yielded a "clumped" or aggregated distribution of crop trees. The lack of aggregation in the chemically thinned stand at the Cariboo was due to a "re-working" of the stand during the thinning operation. This re-working (herbicide injection of those trees that were missed in the first application) was not a standard operational treatment.

Although responses in stand structure and vegetation were summarized over the three replicate study areas, responses of small mammals and relative habitat use by large herbivores were limited to the two replicate areas, Summerland and Kelowna. Sizes of treatment stands at these two replicates were somewhat larger and relevant to mammal populations than those at the Cariboo study area. Both of these replicates had aggregated distribution of crop trees in their respective chemically thinned stands compared with the conventionally thinned stands.

4.2. Stand structure

Diameter growth of lodgepole pine crop trees was similar in the two methods of thinning, but only conventionally thinned stands were higher than those of the unthinned stands. This result was similar to other thinning studies where conventionally thinned stands of lodgepole pine increase in diameter, but not height, compared with unthinned stands (Johnstone, 1985; Cole and Koch, 1995; Cochran and Dahms, 1998). The clumped distribution of trees likely reduced diameter growth in the chemically thinned stands. This clumping of trees was also a likely explanation for the higher density of crop trees (>3 m height) recorded in 1998 than in 1993 in the chemically thinned stands at Summerland and Kelowna (Table 1). Small trees (<2 m height) were not consistently treated in these stands, as they were in the conventionally thinned stands, and their growth into the >3 m height class over the 5-year post-treatment period increased the density of crop trees and provided the horizontal stratification.

The higher tree crown volumes in chemically thinned stands than unthinned stands at Summerland and Cariboo was important for stand diversity (Hayes et al., 1997). These crowns should provide large areas for some species of birds to nest, roost and forage (Hamer and Nelson, 1995; Bailey, 1996). Large crowns and branch structure also provide nest sites for arboreal sciurids such as the red squirrel (*Tamiasciurus hudsonicus*) and northern flying squirrel (*Glaucomys sabrinus*) (Rothwell, 1979; Carey, 1995).

Although overall volume of down wood was similar among treatment stands, it was not surprising that number of wood pieces in the small and intermediate size classes, and decay class 3, were clearly highest in the conventionally thinned stands. Fallen debris from the thinning operation provided the material for this accumulation of down wood.

4.3. Understory vegetation

Thinning by either method had little effect on understory vegetation, at least up to 5-year post-treatment. The decline in structural diversity in the herb, shrub and tree layers in the chemically thinned stands resulted in less vertical stratification. However, this pattern was not noted for the structural diversity of conifers. Although vertical stratification of understory vegetation was altered, horizontal stratification was likely increased owing to the highly aggregated distribution of crop trees in the chemically thinned stands at Summerland and Kelowna. Our lack of a positive response in volume of herbs or shrubs was surprising compared with other studies (Crouch, 1986; Klinka et al., 1996; Thomas et al., 1999). In addition, Sullivan et al. (2001) reported a significant response in volume of herbaceous plant species in pre-commercially thinned lodgepole pine at 5- and 10-year post-treatment.

4.4. Small mammal communities

Similarity of mean abundance, species richness and species diversity among treatment stands suggested that the few significant changes in stand structure attributes had little or no effect on small mammals. Deer mice were most abundant in chemically thinned stands and heather voles in conventionally thinned stands, but other species showed no differences among stands. Similar results were reported for small mammals in thinned and unthinned hardwood stands (Brooks and Healy, 1988). However, in other thinned lodgepole pine stands (10–15 years older) in southern BC, abundance and species diversity of small mammals was positively influenced by stand thinning (Sullivan et al., 2001).

Thus, our hypothesis (i) that abundance and diversity of stand structure attributes (species diversity and structural diversity of herb, shrub and tree layers) and forest floor small mammal communities would increase from unthinned to conventionally thinned to chemically thinned stands was, in general, not supported. Clearly, additional replicates would have strengthened the inferences drawn from our results. Therefore, our conclusions need to be viewed cautiously in light of the limited sample size.

4.5. Large herbivores

Our hypothesis (ii) that relative habitat use by large herbivores would increase from unthinned to conventionally thinned to chemically thinned stands was also not supported. The high use of conventionally thinned stands by deer may have been in response to the higher structural diversity of vegetation in these stands than in the chemically thinned stands. This vertical structure provides forage and cover for ungulates (Lyon, 1987; Nyberg, 1990). The gradient of habitat use suggested that deer were avoiding stands with a clumped dispersion of crop trees. Thickets and patches of dense lodgepole pine provide important habitat for many fur-bearing species such as lynx (*Lynx canadensis*) and snowshoe hare (Koehler, 1990). In our study, hares tended to fit this pattern, but deer did not.

Samples of pellets and pellet groups represented an accumulation over several years. A major assumption was that these fecal depositions occurred in the 5-year period since thinning. This assumption was probably reasonable because deer fecal pellets may decompose in 1–3 years in coastal forested environments (Harestad and Bunnell, 1987). Readily visible pellets were counted on the substrate or vegetation of each sample plot. However, pellet decomposition rates are not known for our interior forest ecosystems. In addition, summer or winter seasons could not be distinguished for this measure of relative habitat use.

4.6. Herbicide treatment

The lack of differences among treatment stands suggested that there were no apparent negative effects of glyphosate herbicide, as an injection system to kill trees, on plant and mammal components of these forest ecosystems. This result is similar to those for broadcast and spot applications of glyphosate in temperate zone coniferous forests (Lautenschlager, 1993; Runciman and Sullivan, 1996; Sullivan et al., 1998; Lindgren and Sullivan, 2001).

5. Management implications

Our results indicate that chemical thinning of young lodgepole pine stands produced an aggregated pattern of crop trees compared with stands subjected to conventional thinning. Diameter growth of crop trees in the chemically thinned stands was similar to that in the conventionally thinned, but also to that in unthinned stands. Although horizontal stratification (aggregates of trees) was enhanced, vertical stratification (structural diversity of vegetation) was less in the chemically than conventionally thinned stands. Abundance and diversity of understory vegetation and small mammal communities were generally unaffected by stand thinning in these particular installations. Relative habitat use by mule deer occurred in a gradient from highest in the conventionally thinned stands to lowest in the unthinned stands. Habitat use by snowshoe hares tended to have the opposite trend. Thus, although there were few statistically significant differences among treatment stands, chemical thinning could be used to develop an aggregated pattern of crop trees in pre-commercially thinned stands to maintain habitat for herbivores such as snowshoe hares and mule deer. Understory plant and forest floor small mammal communities would be maintained in these stands as well. Conventional thinning could also be used to generate aggregations or clumps of trees in thinned stands.

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